Center Innovation Fund: JSC CIF

Safe, High Specific Energy & Power Li-ion Cells

Completed Technology Project (2016 - 2017)

Project Introduction

Today's best, **safe** commercial Li-ion cell designs achieve ~180 Wh/kg, ~500 Wh/L, and 400 W/kg. When accounting for the lightest (1.35) parasitic mass and smallest (2.0) parasitic volume factors of proven battery construction features, this means that at the battery level we need improvements of 144% and 170%, respectively, to achieve our specific energy (>325 Wh/kg) and energy density (>540 Wh/L) performance targets. Today's best commercial Li-ion cell designs offer the promise of a 47% and 82% improvements, respectively, over the State of the Art as shown in Fig. 1 below. Unfortunately, we can't implement these new cell designs, which are safe enough for small consumer batteries but are unsafe for larger manned applications due to the high propensity for them to side wall rupture during thermal runaway.

This proposal offers to overcome this safety issue and enable significant progress towards the Evolving Mars Campaign (EMC) target. We seek our advanced battery designs to be passively propagation resistant to a single cell thermal runaway (TR). Key to this goal is greatly reducing the risk of side wall rupture of the hot thermal runaway products ejected from the cell (a.k.a., ejecta). Side wall ruptures create a blow torch effect which, when impinging on adjacent cells, causes nearly immediate TR propagation in a closely-packed battery designs.

The higher energy content (265 Wh/kg, 725 Wh/L) of the newer cell designs from LG, Panasonic, and Samsung have made them susceptible to side wall ruptures during thermal runaway, rather than venting through the intended vent path in the cell header. This is also due to higher reaction kinetics of the electrochemistry, thinner can walls, tight crimp enclosure of the cell header, and inadequate flow rate through the header vent. Tesla Motors was the first to recognize and address this issue by asking cell manufacturers to produce cell designs with bottom burst disc vents. However, those designs exclusively for Tesla and not available to others. Thus, we must stay with lower performing cell designs or implement structural supporting features for the cells in the battery designs. Both options limit battery achievable specific energy to at best 133 Wh/kg. Being able to safely implement the newest cell designs with bottom vents will enable reaching 196 Wh/kg at the battery level. This 47% improvement would save 24 lbs per each 4 kWh MPCV battery or 96 lbs per MPCV flight or enable 1 hour flight run time for the X-57 electric plane by saving 282 lbs from their 46 kWh battery. Similar volume savings impacts are possible by retiring the side wall rupture risk, because it allows cells to be safely nested together more efficiently. These sizable mass/volume savings and safety improvements are aligned with the needs of the EMC.

Safe, higher performing batteries are well aligned with EMC needs for high specific power, high specific energy batteries, long life batteries, and deep space suit specific energies >235 Wh/kg.

The required vent paths are achieved by scoring a groove pattern in bottom of

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the mild steel can. Although they look simple, achieving a reliably performing bottom vent is not trivial. Weaker designs are excessively susceptible to corrosion, leakage, damage, and poor performance uniformity. The important question that this research project will answer is whether our design will significantly reduce the side wall rupture risk without significant limitations, such as leakage, corrosion, and excessive performance variations.

The scope of the project includes conducting TR tests on similar cells with and without the bottom vent to show the merits of the bottom vent feature. Just 3 months ago, Sony Energy became the first to make a commercially available, high performing design with a bottom vent. We have taken delivery of 400 such SONY cells last month. LG Chem, Ltd., has not publically released a comparable 18650 cell design with a bottom vent yet but is willing to produce small batches of cells with and without them for NASA for this project.

The next challenge is how to trigger TR in a manner relevant to latent defect induced cell internal short circuits, like the ones that are the cause of field incidents of TR. External heating to the point of TR with a heater is known to weaken the cell can and induce a high frequency of side wall ruptures. Slow oven heating of cells is induces cell venting many minutes to hours before TR occurs and dries out the cell prior to the onset of TR. It is questionable whether a cell with less quantity of electrolyte generates the same TR thermal output.

Our implantable wax insulated internal short circuit (ISC) device that the PI co-invented with NREL has been very successful in inducing TR on-demand with just a modest heat input to >57°C to melt the wax and internally short the cell. Without the device, one must heat the cell >130°C to drive TR. Our first implantation in a batch of a very high energy LG cell design (265 Wh/kg) was very successful and reveals that, with the device in the outer winds of the jellyroll, it is very prone to experiencing a side wall rupture. All our previous attempts to structurally weaken cell cans have proven to not be as reliable in inducing side wall ruptures as the ISC device.

The test plan involves four insightful tests. First, we will determine the vent pressures for the top vents and bottom vents of the cell designs by pneumatic testing. Then, we will drive cells into TR, in quantities sufficient to be statistically significant with and without the bottom vent using the ISC device and with no structural support. Next, we will compare the TR thermal output in our cell TR calorimeter. Cells with a bottom vent are expected to eject a higher fraction of the energy rather transferring that energy through the cell can wall. This is important behavior to discern and quantify for high performing, safe battery designs. Finally, we will partner with University College of London via an SAA to perform tomography and capture the TR response with 2D X-ray videos at a phenomenal 2000 frames per second

Organizational Responsibility

Responsible Mission Directorate:

Space Technology Mission Directorate (STMD)

Lead Center / Facility:

Johnson Space Center (JSC)

Responsible Program:

Center Innovation Fund: JSC CIF

Project Management

Program Director:

Michael R Lapointe

Program Manager:

Carlos H Westhelle

Project Manager:

Eric C Darcy

Principal Investigator:

Eric C Darcy

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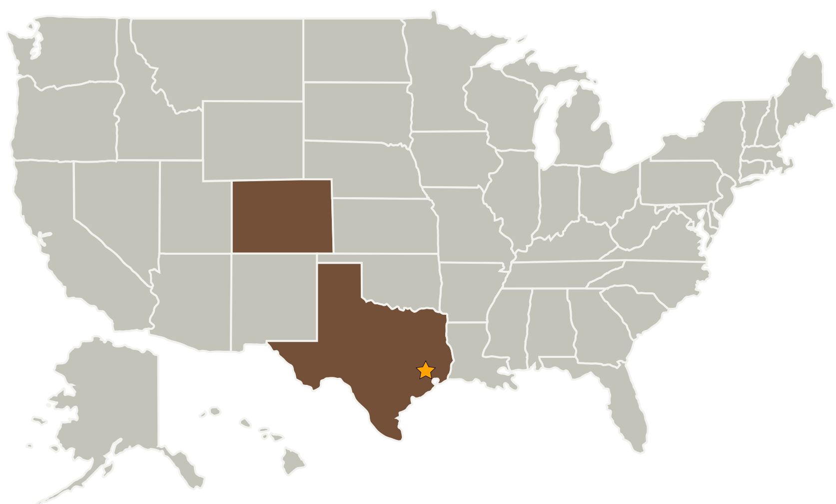
Anticipated Benefits

The main benefits of this research effort are as follows;

a) Obtaining compelling evidence using our internal short circuit device, thermal runaway calorimetry, and ultra-high speed X-ray videography to show the safety advantages of the bottom vent and thicker cell can features.

b) Being able to influence major commercial Li-ion cell manufacturers to adopt and produce safer, higher performing cell designs.

Primary U.S. Work Locations and Key Partners

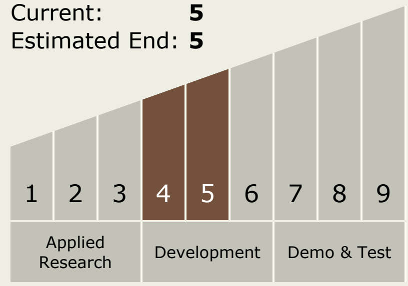


Organizations Performing Work	Role	Type	Location
★Johnson Space Center(JSC)	Lead Organization	NASA Center	Houston, Texas

Co-Funding Partners	Type	Location
LG Chem	Industry	Seoul, Outside the United States, Korea, Republic of
National Renewable Energy Laboratory(NREL)	R&D Center	Golden, Colorado

Technology Maturity (TRL)

Start: **4**
Current: **5**
Estimated End: **5**



Technology Areas

Primary:

- TX03 Aerospace Power and Energy Storage
  - └ TX03.2 Energy Storage
    - └ TX03.2.2 Electrochemical: Fuel Cells

Target Destination

Foundational Knowledge

Supported Mission Type

Push

Primary U.S. Work Locations	
Colorado	Texas

Project Transitions

October 2016: Project Start

September 2017: Closed out

Closeout Summary: It is well known that side wall ruptures (SWR) during TR in Li-ion cylindrical cell designs can defeat al l other measures to prevent propagation in battery designs.This project was the first to combine the implementation of the NREL/NASA Internal Short Circuit Device, TR calorimetry, IR and ultra-high speed X-ray videography to gain unprecedented insights into the factors that drive the occurrence of side wall ruptures. We establish compelling evidence that both the bott om vent feature and thicker can wall greatly reduce the risk of SWRs. We obtained compelling evidence that will influence major commercial Li-ion cell manufacturers into putting those features into their new cell designs. This will benefit numerou s NASA projects like Orion, CCP, X-57, SLS, and many others. It will also improve the performance and safety of numerous automotive, aircraft, drone, and robotic applications.